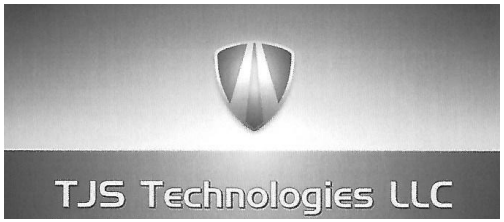

HOM Absorber Design for eRHIC ERL Cavity

SBIR Grant Award No. DE-SC0018466

T. Schultheiss

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Aug 13, 2020

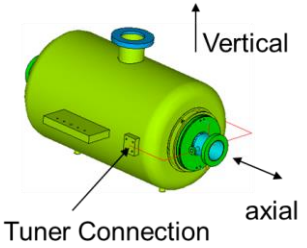
Outline

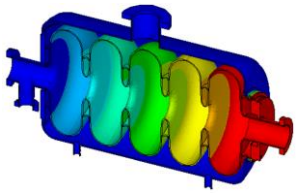
- TJS Technologies LLC (2016)
  - Engineering Services
    - MSU Michigan State University
      - FRIB ASME evaluation of 644 MHz Cavity and Tuner
    - FHI Fritz Harbor Institute
      - Free Electron Laser Deflector Cavity
        - » RF Thermal Analysis – Design, Coupling
    - JLAB
      - SRF Cavity Cooled by Cryocoolers – Thermal Analysis
      - FPC Coupling to Locate the FPC nearer the cavity
        - » (450kW per FPC)
  - Higher Order Mode Absorber SBIR Phase I & II
    - Waveguide
    - Beamline

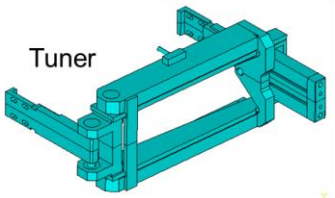
Engineering Service MSU

ASME Structural evaluation of FRIB 644 MHz Cavity and Tuner

- **General Requirements of ASME code Section VIII Division 2 – Design by Analysis**
- **Material Properties**
- **Boundary Conditions**
- **Loads to be Considered**
- **Design By Analysis 2015 Section VIII, Division 2 Part 5 of ASME Code**
  - Protection Against Plastic collapse Part 5.2
    - »Limit Load Analysis Part 5.2.3
    - »Elastic-Plastic Analysis Part 5.2.4
  - Protection Against Local failure Part 5.3
    - »Elastic Analysis 5.3.2
  - Protection against collapse From Buckling Part 5.4
    - –Bifurcation – Eigenvalue Buckling Part 5.4.1.2
  - Protection Against Failure From Cyclic Loading Part 5.5
    - –Experience with comparable equipment operating under similar conditions Part 5.5.2
    - –Ratcheting Assessment – Elastic-Plastic Stress Analysis Part 5.5.7
- **Vibration**
- **Frequency Sensitivity to Pressure**
- **Tuner Evaluation**

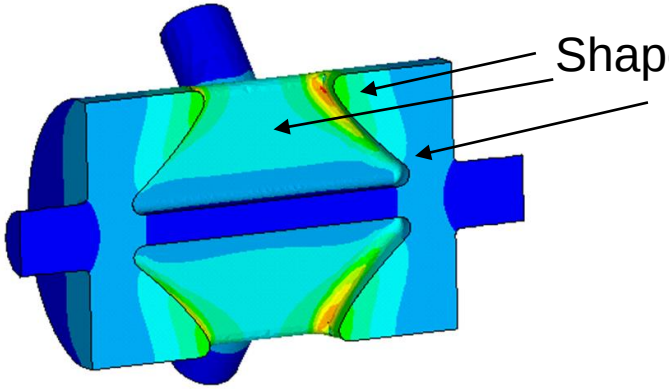




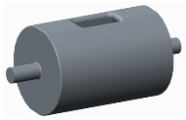


Engineering Service FHI

Develop a Beam Deflector to Provide 2 500 MHz Beams from a single 1 GHz beam 2 Color FEL

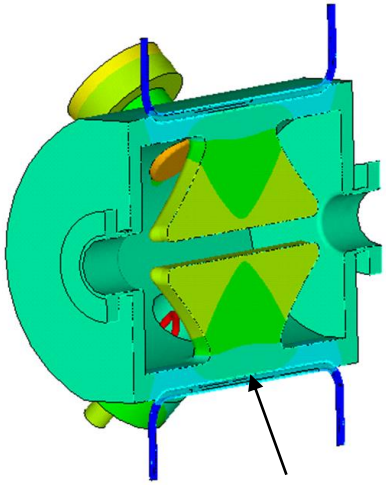


Shape modified for 500 MHz

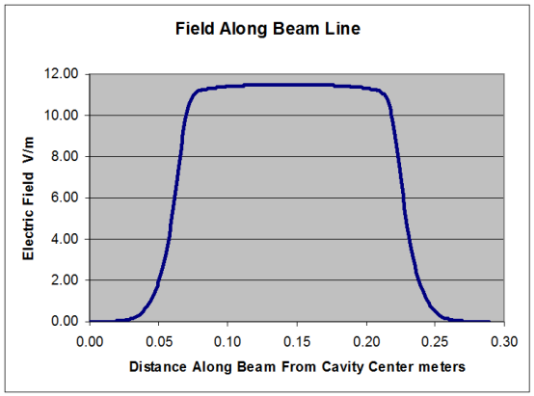


Frequency shift for manufacturing and tuning

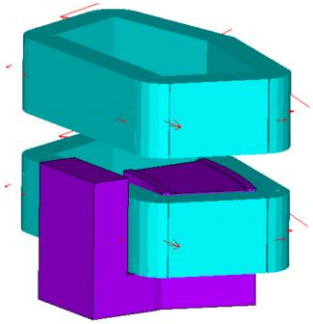
RF Analysis



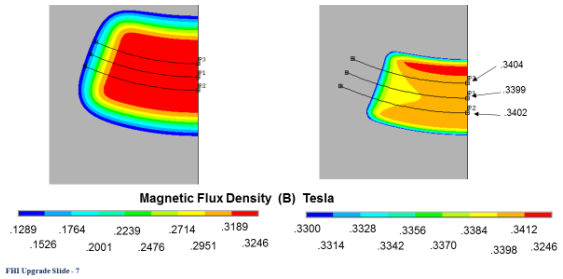
Thermal Analysis



Electric Field Along Beamline

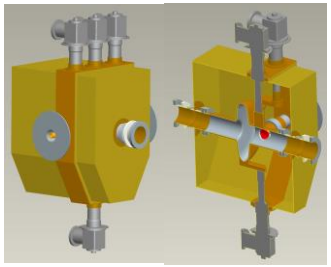


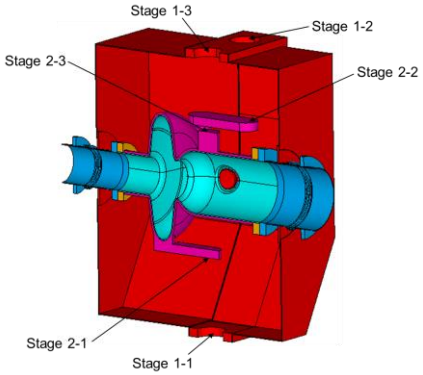
3-D Magnet calcs
Coil geometry
Specification
Field Quality

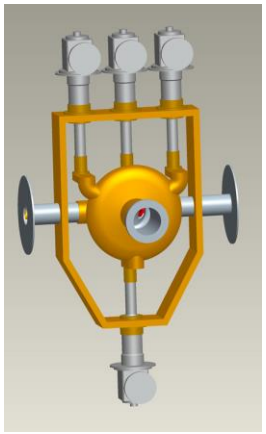


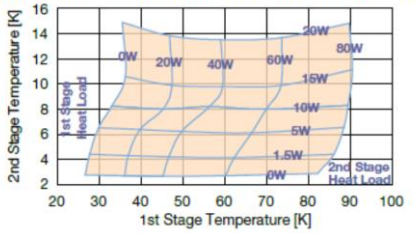
Magnet Analysis

Engineering Service JLAB

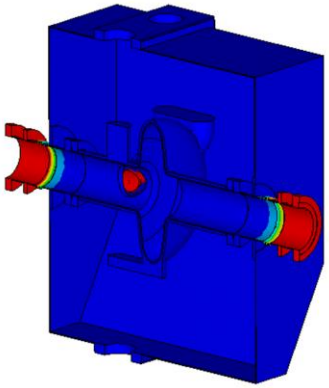




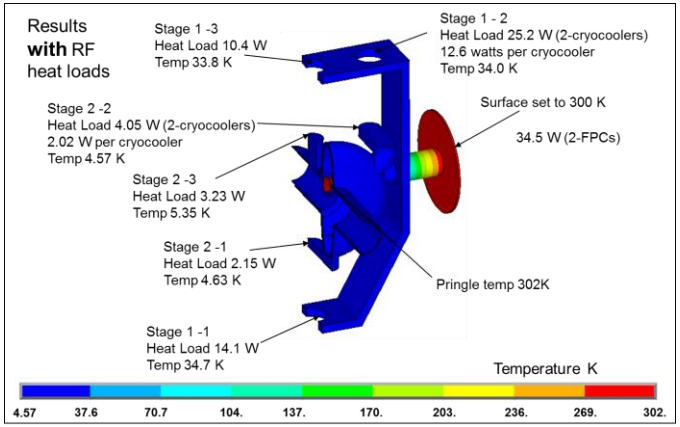


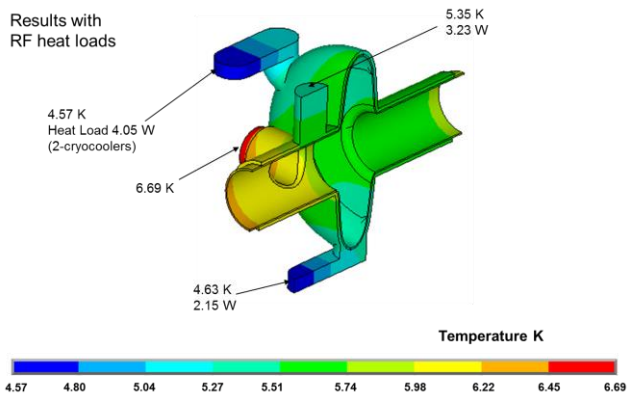


Cryocooler Capacity Map



RF and Thermal Analysis and Coupling for power couplers





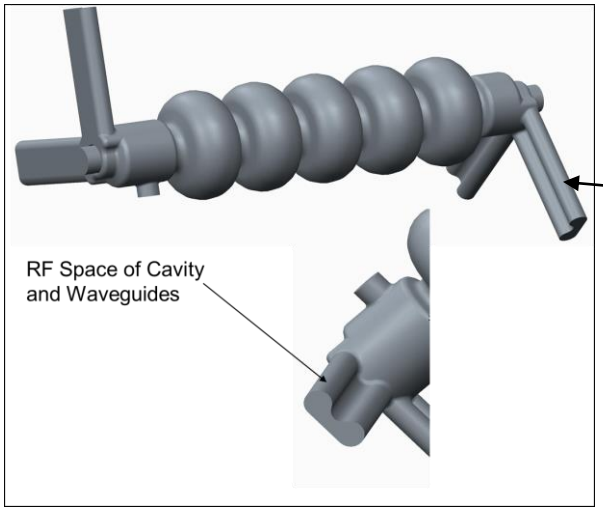
Higher Order Mode Absorber SBIR

- Motivation
  - In 2017 and 2018 BNL was evaluating designs for the electron accelerator in eRHIC, now the EIC, their proposed electron-ion collider
    - It included electron cooling using a multi-cell cavity with high average current and high bunch charge in CW energy recovery mode. This cavity would require a higher order mode absorber with considerable power absorption capability.

Higher Order Mode Absorber SBIR Phase I and Phase II Tasks

- Phase I
  - Define/update HOM specifications with BNL
  - Develop the concept design of the absorber module
  - Perform RF/Thermal and Structural Analysis of the HOM module
  - Develop manufacturing plan and design for the HOM absorber module to a cost level.
- Phase II
  - Manufacture Prototypes
  - Waveguide HOM
  - Beamline HOM

BNL Designed Cavity and B-shaped waveguide



BNL developed a B-Shaped waveguide to suppress multi-pacting and improve impedance decreasing the number of waveguides per cavity
BNL paper SRF2017 TUPB002

Freq	Power
1.21974E+09	9.66546E+02
1.21036E+09	6.10568E+02
1.23850E+09	5.61609E+02
1.24789E+09	5.33179E+02
1.33233E+09	4.14821E+02
1.22912E+09	4.11329E+02
1.90467E+09	2.60402E+02
1.34171E+09	2.13527E+02
1.30418E+09	1.26510E+02
1.20097E+09	1.26386E+02
1.35110E+09	1.25289E+02
1.36986E+09	1.23914E+02
1.29480E+09	1.12858E+02
1.28542E+09	1.05534E+02
1.27603E+09	1.04885E+02
1.26665E+09	1.02065E+02
1.25727E+09	9.97414E+01
1.31357E+09	9.10959E+01
2.56145E+09	7.79565E+01

BNL supplied a set of HOM Freq with its associated power up to 3.1 GHz where HOM power is 1.2 e-5 W

Table to left is the power sorted by power for the first 19 HOM modes

Table supplied by BNL for freq to 3.13 GHz

For analysis HOM power is not degraded by nearby cavity mode power it is determined from beam frequency and used for design limits making the design conservative

Total Power for Freq to 3.1 GHz is 6.01 kW

Model to Determine Tile Heat Loads with curve and shortened tile length to compact geometry

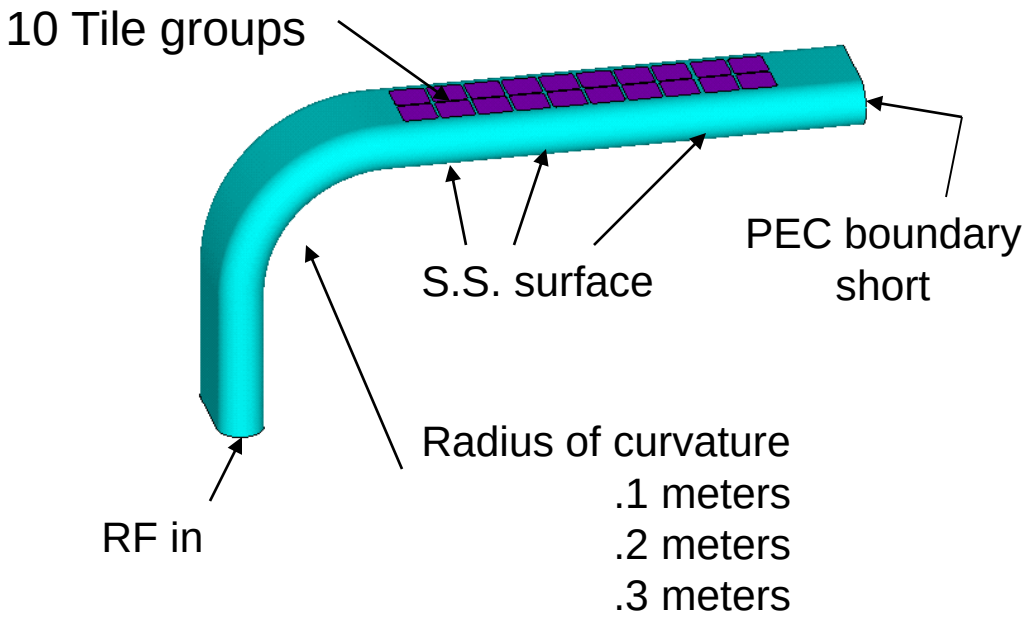
Driven Model

Input Excitation Port

Frequency Dependent permittivity and Loss tangent

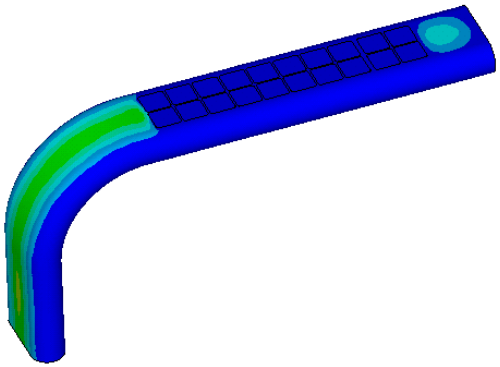
Surface Losses assuming Stainless Steel

Output
S11, Power for each tile group
For each Frequency
Sum Power for each tile group over HOM frequencies

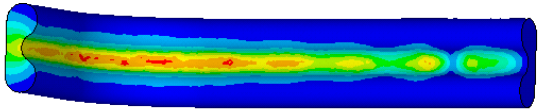


Tile groups with varying thickness
Made from SC-35, graphite loaded

Fields at 1.2197 GHz
Curved Waveguide Radius .1 meters



Power 241.6 Watts (966.5/4)
S11 .0363
ReflP .319 W



Tabulate Results for all evaluated HOMs
4 HOMs per cavity

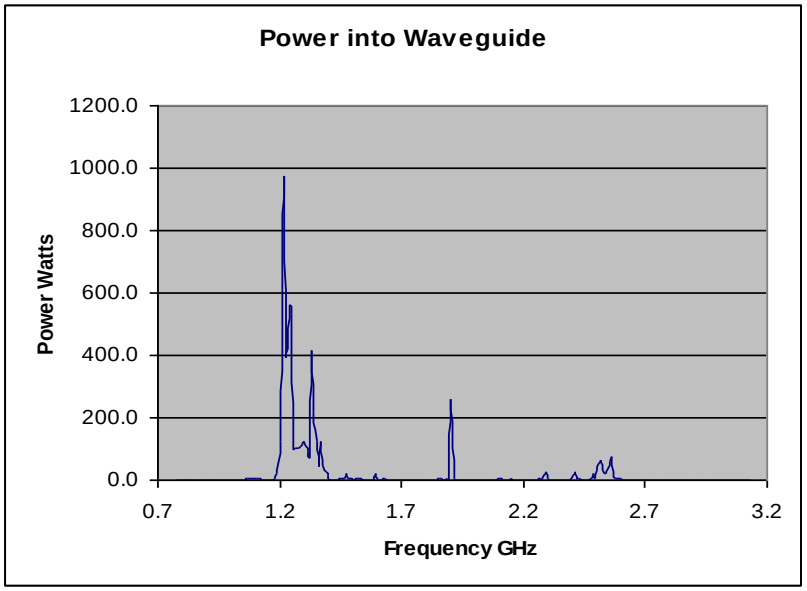
Freq	Power	S11	ReflP	Surf Loads	ld1	ld2	LD3
1.21974E+09	2.41637E+02	3.63340E-02	3.18999E-01	1.34287E+00	2.05640E+01	2.10396E+01	2.38696E+01
1.21036E+09	1.52642E+02	2.50770E-02	9.59898E-02	8.57093E-01	1.29309E+01	1.27258E+01	1.45691E+01
1.23850E+09	1.40402E+02	6.30190E-02	5.57593E-01	7.64159E-01	1.22239E+01	1.29842E+01	1.51182E+01
1.24789E+09	1.33295E+02	7.37400E-02	7.24802E-01	7.18159E-01	1.18679E+01	1.25528E+01	1.50519E+01
1.33233E+09	1.03705E+02	8.02920E-02	6.68568E-01	5.16512E-01	1.37696E+01	1.05113E+01	1.55004E+01
1.22912E+09	1.02832E+02	5.03010E-02	2.60185E-01	5.65519E-01	8.82375E+00	9.26745E+00	1.05817E+01
1.90467E+09	6.51005E+01	1.17180E-01	8.93905E-01	2.25240E-01	1.63844E+01	1.32115E+01	8.47076E+00
1.34171E+09	5.33818E+01	7.12660E-02	2.71118E-01	2.63818E-01	7.34672E+00	5.55251E+00	8.01851E+00
1.30418E+09	3.16275E+01	9.60880E-02	2.92014E-01	1.61430E-01	3.66959E+00	3.07313E+00	4.51124E+00
1.20097E+09	3.15965E+01	2.84580E-02	2.55887E-02	1.79180E-01	2.66583E+00	2.49959E+00	2.93756E+00
1.35110E+09	3.13223E+01	6.06370E-02	1.15167E-01	1.53636E-01	4.44486E+00	3.36306E+00	4.70684E+00
1.36986E+09	3.09785E+01	3.57750E-02	3.96479E-02	1.49785E-01	4.60074E+00	3.59557E+00	4.60617E+00
1.29480E+09	2.82145E+01	9.73070E-02	2.67153E-01	1.45229E-01	3.11195E+00	2.72818E+00	3.91699E+00
1.28542E+09	2.63835E+01	9.65040E-02	2.45710E-01	1.36982E-01	2.76559E+00	2.54465E+00	3.54499E+00
1.27603E+09	2.62213E+01	9.37260E-02	2.30342E-01	1.37344E-01	2.61716E+00	2.52373E+00	3.39182E+00
1.26665E+09	2.55163E+01	8.90190E-02	2.02201E-01	1.34870E-01	2.43513E+00	2.44740E+00	3.16344E+00
1.25727E+09	2.49354E+01	8.23760E-02	1.69206E-01	1.33040E-01	2.28961E+00	2.37570E+00	2.95315E+00
1.31357E+09	2.27740E+01	9.28180E-02	1.96202E-01	1.15280E-01	2.77424E+00	2.23229E+00	3.31811E+00
2.56145E+09	1.94891E+01	8.87690E-02	1.53573E-01	7.36090E-02	3.76744E+00	3.24892E+00	2.35598E+00

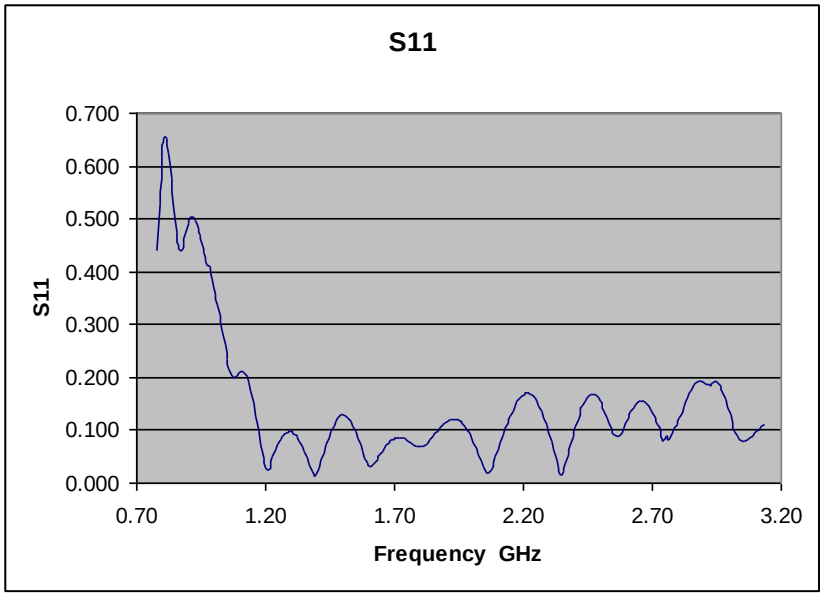
Surface Loss 1.34 W
SS surface elec cond

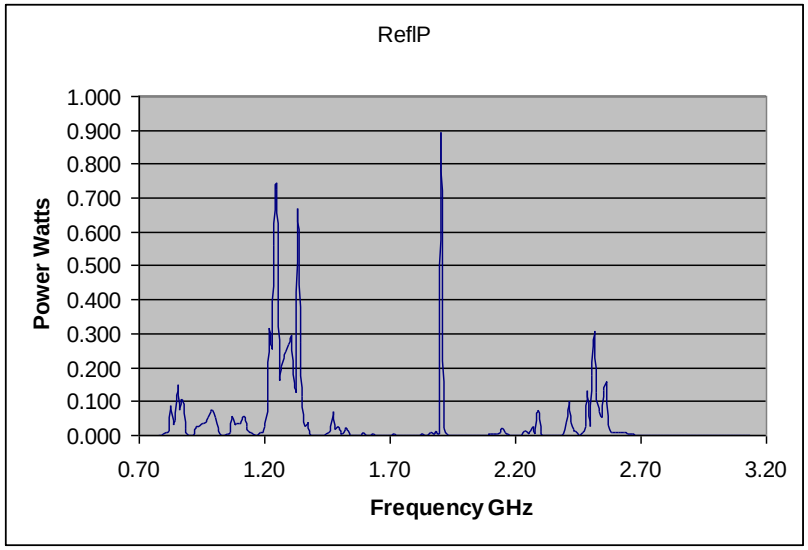
Electric Field V/m

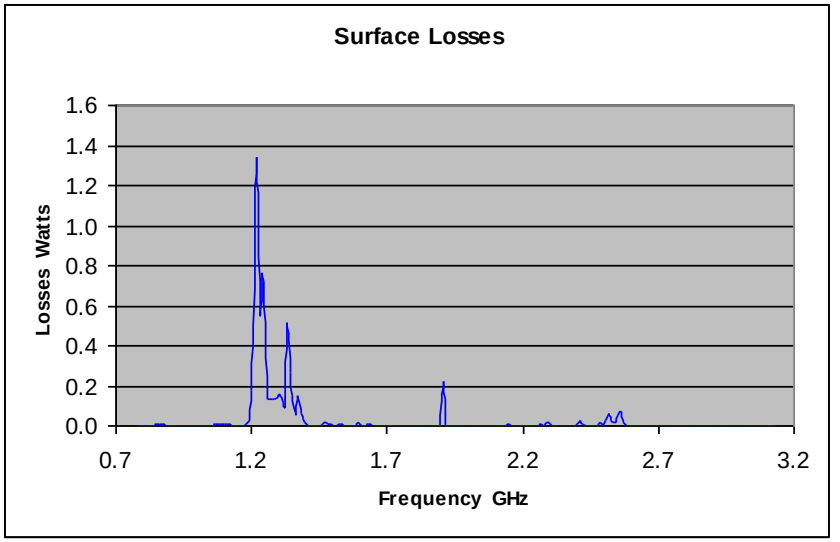
0.0 1780. 3561. 5341. 7121. 8902. 10682. 12462. 14243. 16023.

Power In, S11, Reflected Power, Surface Loss

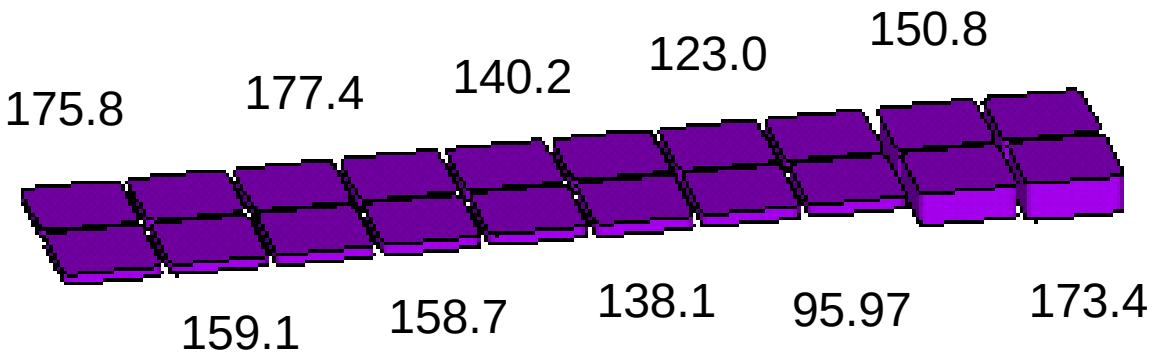








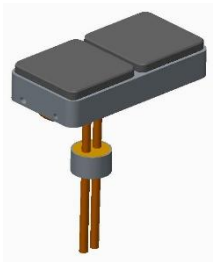
Sum of Power into Waveguide Absorber



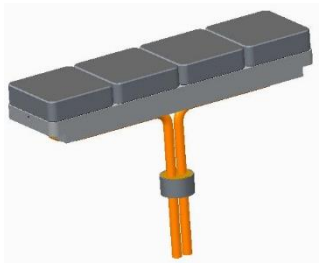
- Initial HOM absorber module geometry
  - 1492.4 W of 1501.5 W is absorbed 99.7%
  - 10 tile pairs
  - Thickness range .200” to .75”
    - 2 at .2”, 1 at .220”, 2 at .225”, 3 at .250”, 1 at .65”, 1 at .75”

Higher Order Mode Absorber SBIR Phase II

- Manufacture HOM Core
  - Can be used for Waveguide or Beamline Absorber

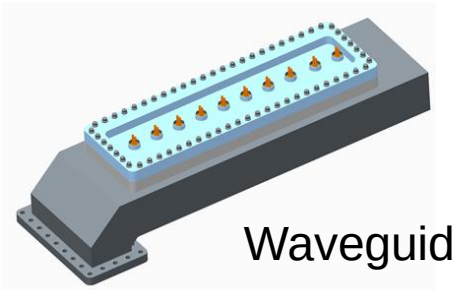


Waveguide core

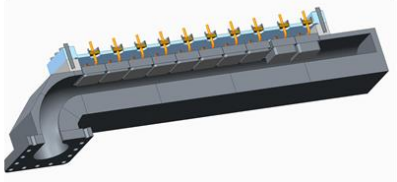


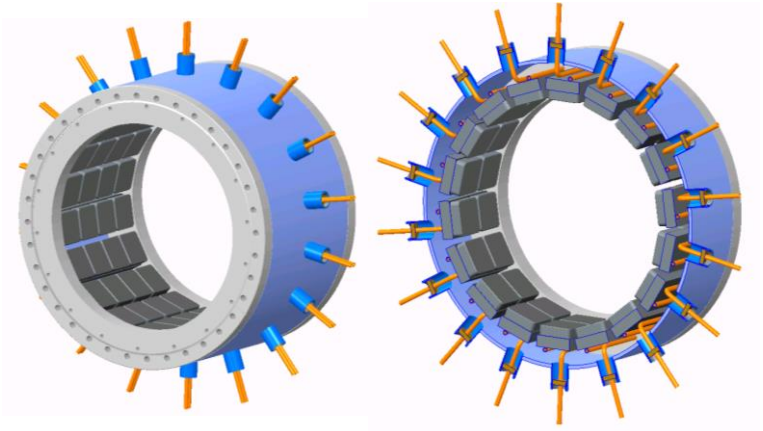
Beamline core

- Manufacture Housing and Assemble Core and Housing



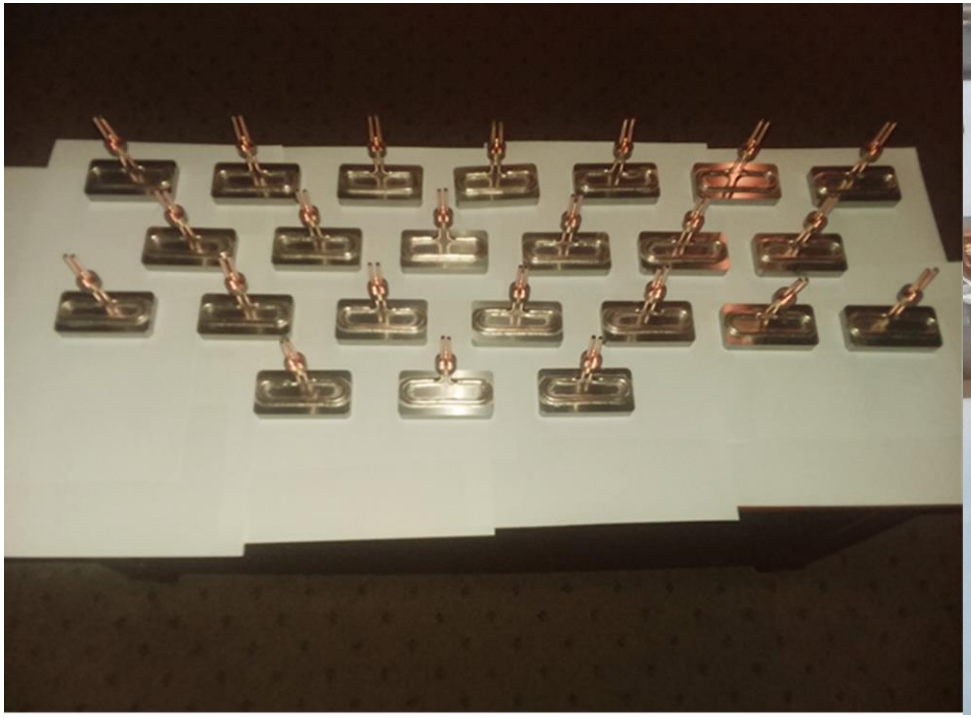
Waveguide HOM





Beamline HOM

Initial Braze Step in Fabrication of Cores



Waveguide Backer Assemblies (without SiC tiles)
Extra assemblies are for Ceramic joining tests

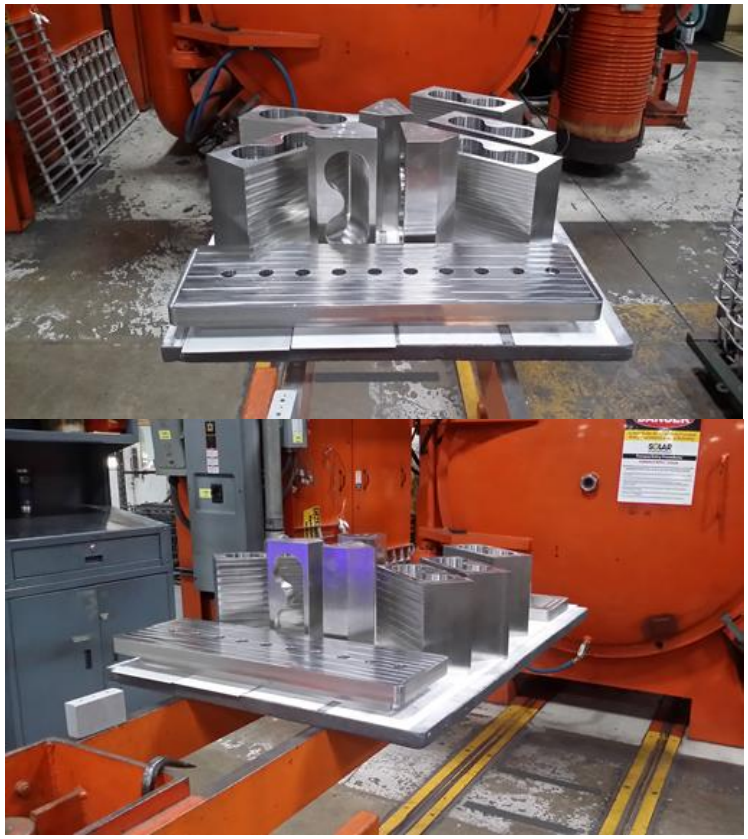
Join Ceramic Tiles to Backers

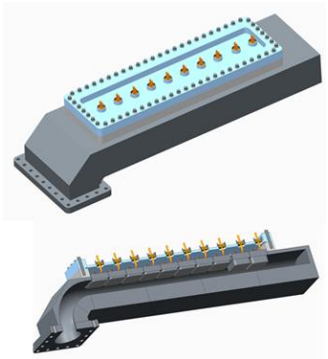
Backer-Tile Assemblies shown after joining

Machining of Waveguide Assembly

Machining of Waveguide Housing Parts

Higher Order Mode Absorber SBIR Phase II





Waveguide parts after heat treat (annealing). Prior to final machining.

Parts stacked with braze alloy - thermocouples applied, ready for intermediate braze step

SBIR Summary

- On Track to complete waveguide and Beamline HOM Absorber by end of Yr2
- Using HOM core can develop many geometries to accomplish HOM absorption
- Size of beampipe absorber can be accommodated by adding more cores circumferentially